Materials Science and Engineering A 523 (2009) 7–12

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Effects of age heat treatment and thermomechanical processing on microstructure and mechanical behavior of LAZ1010 Mg alloy

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ARTICLE INFO

Article history:
Received 2 October 2008
Received in revised form 27 February 2009
Accepted 2 July 2009

Keywords:
Mg–Li alloy
Age hardening
X-ray diffraction
Thermomechanical treatment
Work-hardening rate

ABSTRACT

An Mg–Li–Al–Zn (designated as LAZ1010) alloy containing about 10 wt% of Li has been prepared by melting and solidification in a carbon steel crucible, and extruded at a billet preheating temperature of 200 °C with an extrusion ratio of approximately 29. Effects of age heat treatments and thermomechanical processing on microstructures and mechanical properties were performed in this study. Hardness, optical microscopy, X-ray diffraction studies, and tensile testes were carried out to explore the variations in microstructures and mechanical behaviors during processing. The results showed that LAZ1010 alloy presented age hardening effect at temperatures below 50 °C. Rapid decrease in hardness with aging temperature at intermediate temperatures should be resulted from the transformation of θ phase into the equilibrium phase AlLi. Kocks–Mecking type plots were used to illustrate different stages of work hardening of the cold rolled specimens. The results indicated that cold rolled LAZ1010 alloy showed stage III and stage IV work hardening behaviors.

1. Introduction

Alloying Mg with lithium yields a lightest structural metal of Mg–Li alloy. The Mg–Li phase diagram [1] indicates that when the Li content is between ~5.5 and 11.5 wt%, the BCC structured β phase of the Li solid solution coexists with the HCP α phase of the Mg solid solution. As the amount of Li added to the Mg–Li alloy increases, the α phase still possesses HCP structure, but the crystal lattice axes ratio, *c*/*a* decreases such that slip between crystal planes become less difficult [2], the coexistence of the β phase makes the Mg–Li alloy possible to be cold worked. The β single phase structure could exist in Li contents greater than 11 wt%. However, the mechanical properties of Mg–Li alloys are not particularly favorable for structural applications due to its low tensile and yield strength. Various third elements have been added to the Mg–Li alloy systems to explore the effect of the addition of a third element on the mechanical properties and formability [3–8].

Mg–Li alloys with zinc or aluminum can be strengthened by age hardening [8–13], Al addition has been selected as a precipitation and solid solution hardener, and Zn could also improve the cold formability [14]. The major hardening phase in Mg–Li–Al system is $MgLi_2Al$, θ phase, which transforms to an equilibrium phase AlLi on overaging [7,13,15]. Mg–Li–Zn system could be strengthened by $MgLi_2Zn$ phase with high Zn addition [4,12]. $MgLi_2Zn$ phase, a metastable structure [16], decomposes partially into MgLiZn phase after precipitation, therefore, the hardening and softening effects of the Mg–Li–Zn alloy are basically determined by the precipitation and decomposition of $MgLi_2Zn$ phase.

Aging behaviors of Mg–Li–Al and Mg–Li–Zn alloys have long been investigated [4,7,11–13,15]. However, few studies have been carried out to examine the effect of thermomechnical processes on the properties [16], though it is important to the development of an Mg–Li alloy with suitable mechanical characteristics. In this paper, an Mg–Li–Al–Zn (designated as LAZ) alloy containing about 10 wt% of Li was prepared with precision casting equipment, followed by extrusion. Main emphasis was placed on investigating the effects of heat and mechanical treatments on the properties of the LAZ alloy.

2. Materials and experimental procedures

2.1. Alloys

The Mg–Li alloy was melted in a high-vacuum electric induction furnace under an argon atmosphere and then cast into an ingot with a cylindrical shape of 200 mm in diameter and 400 mm in height. The analyzed chemical composition of the cast alloy by use of induction coupled plasma (ICP) and Spark Optical Emission Spectrometry (Spark-OES) apparatuses is given in Table 1 (designated as LAZ1010). The cylindrical ingot was then extruded into a plate of 110 mm in width and 10 mm in thickness at a billet preheating temperature of 200 °C.

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doi:10.1016/j.msea.2009.07.008

Table 1
Chemical composition of the Mg–Li–Al–Zn alloy (wt%).

Designation	Li	Al	Zn	Mg
LAZ1010	10.31	1.03	0.47	Rem.

2.2. Age heat treatment and thermomechanical processing

The as-extruded plate was solution heat treated at 400 °C for 1 h followed by quenching, heat treated specimens were then aged at room temperature, 50, 100, 150, and 200 °C for 1–80 h to study the effect of age heat treatment on the microstructures and mechanical properties.

The heat treated specimens were cold rolled with the reductions of 20, 40, 60, and 80%. Reference specimens for comparison were directly cold rolled from the extruded plate with the same reductions as used for the heat treated specimens to explore the effect of heat treatment on cold working.

2.3. Tensile tests

Tensile tests with standard rectangular specimens manufactured based on the ASTM B 577 M specifications were carried out along the extrusion and rolling direction on three samples for each test. The gauge length and width of the tensile specimens were 25 and 6 mm, respectively. The specimens were tested at room temperature with an initial strain rate of $1.67 \times 10^{-3}\ s^{-1}$.

2.4. Metallographic inspection

The specimens for microscopic examination were prepared by conventional metallographic techniques. The polished specimens were etched for 1–5 s in the etchant of 5 g picric acid, 10 ml acetic acid, 95 ml ethyl alcohol. Optical microscopy (OM) was used to examine the microstructures. X-ray diffraction (XRD) was utilized to identify the phases in the microstructures. Grain size was measured by the linear intercept method according to ASTM standard E 112-88.

3. Results and discussion

3.1. Analysis of the microstructure

Fig. 1 shows the as-extruded structures of LAZ1010 alloy. The alloy contains both the major β phase and minor α phase. The Li content of LAZ1010 alloy is about 10.31 wt%, which is near the region of single β phase, so only a few dispersed α phase particles are shown in the microstructure, as demonstrated in Fig. 1(a), and most of the α particles are located in the grain boundaries, as shown in Fig. 1(b). Fibrous structure was not observed for the extruded plate. Dynamic recrystallization should have taken place during extrusion. The average grain size is approximately 85.4 μm. Dynamic recrystallization of β phase was also found in the as-extruded Mg–8.7Li and Mg–8.8Li–6.4A1 alloys [17].

The extruded plate was then solution heat treated at a temperature of 400 °C for 1 h. Fig. 2 demonstrates the heat treated microstructures of the alloy. The α particles, which were located in the grain boundaries in the as-extruded specimen, have been dissolved and no noticeable grain growth could be found in the heat treated structure. The average grain size is about 86.7 μm.

The X-ray diffraction (XRD) patterns obtained from as-extruded and heat treated specimens are given in Fig. 3. It shows that the as-extruded specimen comprises α-Mg, β-Li, $MgLi_2Al$ (θ), and AlLi structures. Since θ phase is the major hardening phase in Mg–Li–Al systems with low Zn content and transforms into an equilibrium phase AlLi [7,13,15], precipitation might take place during solidification to produce precipitation phases of θ and AlLi in the as-extruded microstructure. Fig. 3 also indicates that the precipitation phases of θ and AlLi were dissolved after heat treatment. It is of interest to note that the relative intensities of the α phase in the heat

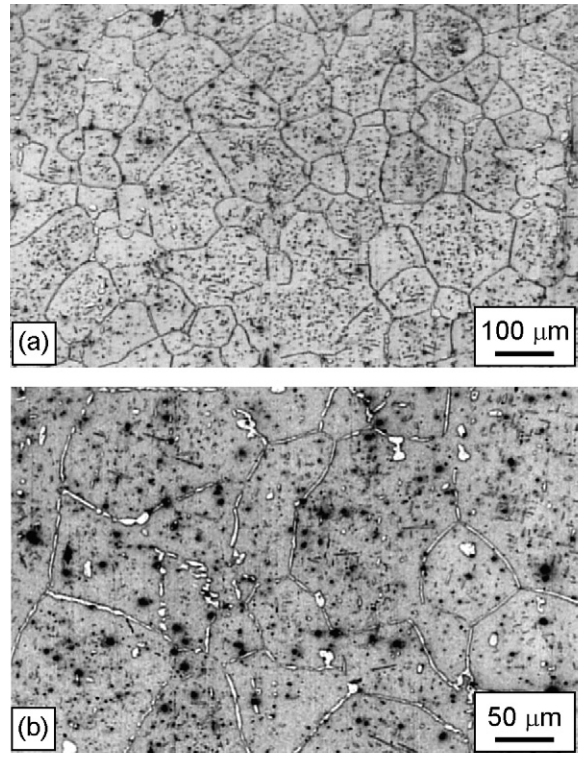

Fig. 1. Optical micrographs of the as-extruded microstructures. (a) LAZ1010 alloy, (b) LAZ1010 alloy on a larger scale.

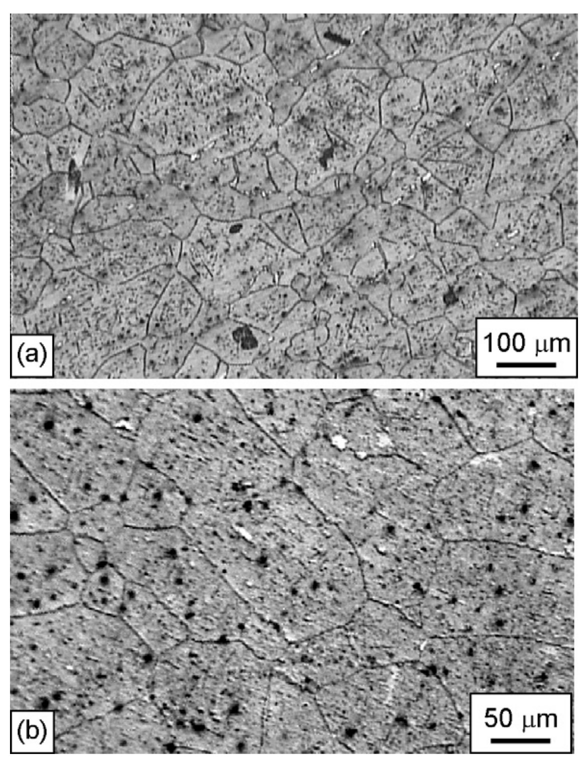

Fig. 2. Optical micrographs of the annealed microstructures. (a) LAZ1010 alloy, (b) LAZ1010 alloy on a larger scale.